AN APPROACH TO ENVIRONMENTAL
CONTROL AND MECHANICAL SYSTEMS
IN AN ARCHITECTURE CURRICULUM

by

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ABSTRACT

Environmental control, an inseparable part of architecture, is in most schools the weakest part of the curriculum. M.I.T. is no exception. The object of this thesis is to propose an approach to teaching these courses an in particular, to propose a revision of the present courses at M.I.T. which will implement this approach.

The inadequacy of these courses stems from the compartmentalizing of the subjects isolating them from architectural design, an engineering approach to the material, and a general lack of consideration of the environmental control issues in the design studios. In addition, there are no courses which deal with illumination, plumbing, electrical systems, or vertical transport systems. Acoustics is the only facet of environmental control which is adequately treated.

Curriculum revision to solve these problems in a few other schools are discussed and two alternative methods of teaching the material are considered. Finally, an approach is presented which retains the class sessions separate from the design studio and is organized to stress the fundamentals and the architectural implications of environmental control. This approach can be characterized as a separating of the theory from the equipment and dealing with all of the environmental forces in parallel as much as possible. A general topic outline is presented and methods of teaching are discussed.

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PREFACE

During the early stages of research for this thesis, I discovered that a rewriting of the air conditioning course, as I originally intended, would only be a patchwork solution. The problem is not only with one course but with a lack of a coordinated set of courses dealing with all of the environmental control issues and the relationship of these issues to the whole architectural curriculum. What follows, therefore, is more comprehensive but less specific than a revision of the air conditioning course would have been.

During this research I acquired an awareness that architectural design need not be as random as it seemed to me in my four years and that architectural education would profit by being more objective and by dealing more with the teachable subjects.

I very much appreciate the help given to me by the many people with whom I have discussed this problem, in particular Murray Milne, Robert B. Newman, Edward B. Allen and Charles Tiers, with whom I corresponded. Invaluable was the encouragement and editing of my wife Emilie. Finally, to Nancy Jones, who types the manuscript, thank you.

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CHAPTER I

Introduction and Objectives

The importance of science and technology as a part of an architecture curriculum is undeniable. There is no school of architecture which does not have technical subjects in its program. At M.I.T., in particular, one would expect that it would be a vital part of the curriculum. Indeed, the official descriptions of the M.I.T. School of Architecture claims it:

> ...as an integral part of a scientifically oriented university, the School is able to nurture interactions between visual thinking and the physical sciences, mathematics, and logic, technology, the social sciences, and the humanistic arts. These interactions give contemporary meaning to design; without them, form-making rests at the level of irresponsible gesture.[1]
>
> The information and the technical methods for designing and executing solutions in both architecture and planning stem largely from the scientific revolution, and the School therefore benefits enormously from its placement in a scientific university.[2]

Unfortunately, this interaction seldom occurs, particularly in the area of environmental control.

One might argue about whether the technical subjects should be taught in school or are better learned in practice after

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[1] Anderson, L.B. "Undergraduate Education in the School of Architecture and Planning," one of a set of leaflets describing the curriculum.

[2] Anderson, L.B. M.I.T. General Catalogue, 1968-69, p. 87.

graduation, but the fact remains that some think it is important, and adequate courses should be made available in schools of architecture where these subjects can be learned.

It is interesting to note the result of a recent A.I.A. survey (c. 1967) of practicing architects which yielded the fact that interest in continuing education in architectural technology exceeded that of any other part of professional activities.[3]

The object of this thesis is to look at the problem of teaching the technical subjects, and in particular environmental control and related mechanical systems--often the least adequate of the technical courses--with the intent of developing an approach which will make the teaching of environmental control relevant to the architecture curriculum at M.I.T.

How can the teaching of environmental control in the architecture curriculum be improved? The objective of the architecture curriculum is to provide the means for students to acquire knowledge, skills, and an understanding of architectural design concepts and to develop attitudes about applying

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[3] Small, Robert E. "Inter-University Conference: Education Innovation for Architectural Technologies."

the knowledge, skills, and concepts in solving environmental problems.

There are several ways to define the environment. Broadly speaking it can be considered the sum of all the forces, energies, or elements which are sensed by the human being, those which affect the human being but are not sensed, and those which affect physical (inanimate) objects. One way to describe them, as a scientist might, is:

. the electromagnetic spectrum including radio energy, heat, infra-red, visible light, ultra-violet, and the high energy x-rays, cosmic rays, etc.

. the acoustic spectrum including audible sound, ultra-sonic wave propagations,

. the energy of the surrounding medium which includes the atmosphere and all its constituents: oxygen, nitrogen, carbon dioxide, the trace gasses, water vapor, pollutants both solid and gaseous, rain, snow, hail,

. the forces which act upon a mass (in the Newtonian sense) which include gravity, inertia, wind.

The environmental designer, however, is more concerned with the human response to the environment and therefore, rather than the energy of the environment, it might be said that it is the human perceptions of the energy which are important. These are not as objectively quantifiable and measured as when defined in scientific terms because of the variation among individuals in perceiving the energy.

In perceptual terms, the environment includes:

. the visual environment including the spatial perception of physical objects by means of light and illumination

. the thermal environment including heat, humidity, moisture, temperature,

. the auditory environment

. the olfactory, smell-taste, environment,

. the force perceptive environment including the tactile, kinesthetic, proprioceptive perceptions.

The architect has traditionally been concerned primarily with the visual-spatial realm: the kinds of spaces that are formed, the relationship of one space to another, and the relationship of the activities to one another. The other elements of the environment are usually considered only secondarily (sometimes not at all) and these aspects of the design are turned over to engineering consultants to solve.

Architecture is also evaluated, at least by the profession, primarily by its visual-spatial qualities and the functional relationships of the spaces formed. This has implications about the architecture curriculum, vis-a-vis the technical subjects and the design studios. In general, architects are poorly prepared to deal with the technical aspects of architectural design (i.e., structural, thermal, acoustic and mechanical equipment). This is not surprising since the technical courses at most architectural schools are poorly oriented toward the architect, and the design studios give little consideration to the technical aspects of design. Which is cause and which effect? Which is the chicken and which the egg? Each seems to feed upon the other.

The environmental control subjects are usually compartmented to deal with the environmental control issues independently of each other with little, if any, co-ordination among them or with the design studio. At the same time the design studios make little effort at bringing these issues into the design problems.

The courses are usually taught by engineering professionals who have not had architectural training and are taught from the engineering point of view, that is, mathematically.

Typically, the concepts are explained and demonstrated by means of formulae, and examples are mathematically solved.

Some of the attitudes which the engineers have about architecture and architects lead to a watering down of an engineering course. Since architects are usually less able to deal with mathematical conceptualization and are more visually oriented, it is thought (apparently) that they will have difficulty in understanding the principles. Consequently, most of the emphasis is on the typical solution to environmental control problems, rather than on the nature of the problem and its basic principles. There is also a failure to appreciate the architect's function in the building process. The attitude is frequently that the vital parts of the building design are solved by the engineers, and the architect adds the "aesthetics."

This mathematical, engineering emphasis, and the attitudes of the people teaching the courses contribute to the student feeling that the environmental control subjects are irrelevant to architectural design and encourages the dichotomy of the two. In order to eliminate the dichotomy between environmental control and architectural design, the orientation and attitudes will have to be changed. One can be accomplished by changing the organization of the material to approach it from the architectural point of view. The other can only be solved by having the subjects taught by people who understand the role of the architect. These are the issues which this thesis intends to cover.

CHAPTER II

Existing Courses at M.I.T.

In the curriculum at M.I.T. the environmental control courses suffer from the failings mentioned in the previous chapter. In addition to the structures sequence, there are four required subjects: 4.402--Building Processes, 1.02--Engineering Materials, 2.644--Environmental Control-Air Conditioning, and 4.43--Environmental Control-Acoustics. Each of these is taught independently of the others and in no planned sequence, except that it is recommended that "Building Processes" be the first of the four and be taken in the first year. The Engineering Materials and Environmental Control-Air Conditioning courses are taught in the Civil and Mechanical Engineering Departments respectively. The other two are taught in the Architecture Department. There are no courses which cover illumination, electrical systems, plumbing, or vertical transportation systems.

Of these four courses, only the Acoustics course is successful in holding the students' interest and providing information which they retain and find useful in the design studios. If student reaction be a measure of the value of a course, the other three would be of negligible value. The courses are considered by many of the students as those which must be tolerated, not very relevant to the things in which they are interested (such as architectural design), and on which only minimal effort need be expended. The reaction to the Air Conditioning course has been so strong in the past few years that it was this year eliminated as a required course. Not unexpectedly, no one signed up for it.[4] Although student reaction to the courses is not a conclusive measure, it does have implications about the way the courses are being taught and must be taken into account.

The Building Processes course, taught by a building engineer recognized in this country as an authority in the field of building research, is a collection of many topics related to the design and construction of buildings. Some of these topics in the order in which they have been presented are: sun's energy, humidity, Olgyay's comfort chart, climate, transmittance of window glass, foundations, ground water, piles, soil structure, materials of construction, strength, durability, dwelling house construction, wood frame construction details, wind loads, nailing, roof structure, steel frame construction types of steel, fabricating techniques, connections concrete types, slump test,

[4] To fill the gap, Professor Murray Milne has been coming once a week for a two-hour seminar to teach parts of the Yale course. A description of this course is given in the next chapter.

placing of concrete, reinforcing, masonry construction, walls for excluding environment, insulation, wall coverings, paints, plastering, windows, details of window construction, flues, flashing, stair proportions, stair framing, thermal energy sources, and critical path scheduling.

Most of these topics are important for the architect to understand, but they are too numerous and occur too soon in the four year program. Consequently, they are covered too briefly and in insufficient depth to be useful and relevant to architectural design. The material covers a variety of theoretical topics and practical details. The energy of the sun's spectrum, the definitions of humidity, and the strengths of different materials are covered along with topics like wood framing details, nailing details, and methods of applying wet plaster. This organization of the material makes it difficult for the student to place it in a larger context and treat it in a way other than as isolated facts.

Environmental Control-Air Conditioning, taught by a Mechanical Engineering professor whose field is heating and air conditioning, is a course which is oriented toward the engineering approach to the problems and the equipment used in the solutions. Much time is spent on computations of heat loss, heat gain, infiltration through cracks, sizing of radiator elements, and friction losses in pipes and elbows. There is little emphasis on the perceptual responses or on the formal implications which thermal control can have on architectural design. It remains an isolated, unrelated course.

Engineering Materials, taught by a Civil Engineering professor, is an adaptation of a course which is taught to civil engineers, covering topics which are "important to civil engineers."[5] The main concern is on the structure of materials and on their structural behavior.

Environmental Control-Acoustics, on the other hand, is considered a much more relevant and useful course. The reasons for this are the teacher's background and experience, the content of the material he presents, and his personality. He was trained both in architecture and in science and is presently one of the world authorities on architectural acoustics. Having architectural training gives him an understanding of the aims of architecture, the function of the architect and the nature of the information the architect needs to intelligently incorporate acoustic principles into architectural design.

[5]See course description in Appendix.

The course format is three class sessions per week with occasional field trips. The content of the course is an initial presentation of the few pertinent formulae which describe the behavior of sound and an explanation of this behavior through some computational problems and demonstrations. The rest of the course is concerned with expanding on these principles with many examples of both good and bad solutions to acoustic problems.

The teacher's extensive consulting experience gives him a vast fund of examples with which to demonstrate these principles. Not infrequently he will deviate from the scheduled topic to explain an acoustic problem he has just encountered during a consulting trip. His lecturing style--enthusiasm, unequivocal judgments of acoustic failures, and showmanship at demonstrating sound with his voice--is not an insignificant factor in the success of the course. Though his personal qualities are an advantage in teaching a course of this nature, they need not be a requirement. The fact that he teaches acoustics in many of the architectural schools in this country is an indication of the success of his teaching.

The result of the present program in the environmental control courses at M.I.T. is that (with the exception of

Acoustics) the students have a poor understanding of these subjects and consequently give them minimal consideration in architectural design. The design studios do little to encourage more consideration of these subjects. Discussion of these issues seldom comes up in juries and the attitude that they are an incidental part of architectural design is thereby unwittingly encouraged.

CHAPTER III

Curriculum Revisions in Other Schools

For several years there has been increasing concern among architectural schools about the teaching of the technical material in the curriculum. In 1966 there was a conference at Washington University in St. Louis, jointly sponsored with the A.I.A., entitled "Education for Architectural Technology." In 1967 the University of New Mexico sponsored, jointly with local industry, a "Building Technology Workshop." In 1968 Harvard held a conference called, "Education Innovation for Architectural Technologies." The A.I.A.-A.C.S.A. has also devoted time to it in the Cranbrook Seminars and space in the A.I.A. Journal.

Many schools are in the process of revising their curricula including making improvements in the technical parts of their curricula. The results of a questionnaire sent out prior to the 1967 University of New Mexico workshop showed that 38 of 77 schools replying had either completed or were in the process of reorganizing their technical curricula.[6] Among the schools which have already made changes in their curricula to improve the teaching of the environmental control courses are Yale University, the University of

[6] Gathman, Walter A. "Building Technology Workshop."

California at Berkeley, the University of Washington, Virginia Polytechnic Institute, and the Bartlett School at University College in London. A description of some of their courses will indicate the approach these schools have taken.

The present program at Yale was set up in 1966-67 by Murray Milne, based on his previous experience in teaching at the University of Oregon. Quoting from his presentation at the 1967 conference at the University of New Mexico:

> First, I've tried to deal with theory rather than equipment. This approach can be characterized as working from a human out rather than the equipment in. We start by discussing the human's sensory processes and how they respond independently to the stimulation of various types of energy. We then discuss the comfort range corresponding to each type of energy, and how the architect can use physical form and other means to maintain all energy levels within the human's comfort range. Finally, we study alternative types of equipment which will solve the environmental control problems.
>
> ...I try to use measuring devices and instruments to illustrate various phenomena right in the classroom (e.g., illumination meter, sling psychrometer). I also invite experts who bring in equipment, pass it around the class and answer questions about their fields.
>
> The central idea is that I first develop an understanding of the human sensory processes and demonstrate that in fact they are responding independently to various kinds of energy in the environment, and further than the designer can mediate all of these different energy forces in the environment that are sensed by the human, and finally that it is this mediation or "design" that is the very essence of environmental control.

> The intent of the various assignments I give is to arouse the student's curiosity, so that he will <u>want</u> to learn. These problems are structured as <u>much</u> as possible so that he will actually <u>discover</u> something for himself, and each man discovers something a little different. 7

The format of the course is two hours of lecture and one hour of seminar each week. In the seminars, the reading and problem assignments are discussed and some principles are demonstrated. The whole sequence is broken down into minicourses of about six weeks each and cover thermal control, light energy, and acoustics. Another course in a later term concentrates on the equipment, and is taught by a practicing engineer.

This course has not had unqualified success so far, although it would be difficult to blame it on the structure and format. It is only in its second year and because of the poor quality of past courses and the attitude that environmental control is virtually incidental to architectural design, there is still a traditional resistance among the students to the technical courses.

At the University of British Columbia, the program was revised in about 1962 by Charles A. Tiers and is still undergoing change. His approach has similarities to the Yale program. In a paper presented at the A.I.A.-A.C.S.A.

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7 Milne, Murray, "Environmental Control Curriculum at Yale."

Teacher Seminar at Cranbrook in 1965 he explained this approach.

> In general the course stresses the principles of science related to various environmental forces and phenomena in an effort to convey understanding (1) of the nature and behavior of the forces and (2) the resultant performance of the materials, components and systems which comprise the fabric of the building. In essence this approach emphasizes <u>why</u> a building may be expected to respond in predictable ways under the impact of these forces rather than <u>how</u> it may be constructed in conformity with the highly transient norms of practice, custom or style. I have divided the broad field of building technology into two areas, which I call building science and building practice. This distinction relates to the treatment of both the materials and the methods of building. In my view it is important to make this distinction and to realize the differences and the connections between knowledge and skill, between theory and practice, both of which are vital in the truly professional education of an architect....The emphasis on theory and principle through building science precedes and thereby provides a firm foundation for the information and practical decisions which are necessary in design and construction....
>
> Thus, the first phase of my course attempts to identify the various 'forces' which impinge on the building and to understand the response of the building as a whole and in its major parts as a kind of complex control mechanism. Most of the emphasis is placed on the nature and behavior of the environmental forces and particularly on those related to climate, but other phenomena exist which may appropriately be treated as 'forces' in this context.... [8]

The topics which are covered in this course are: structural adequacy, dimensional stability, exclusion of water, thermal control, sound insulation and propagation, daylighting

[8] Tiers, Charles A. "One Approach to Building Science."

and sun control, and fire protection. The subject of buildings materials is covered concurrently and in parallel fashion, i.e., they are considered in terms of their characteristics and performance in relation to movements, thermal behavior, fire risk, sound absorbtion and transmission, mechanical properties and problems of weathering and durability.

Another school which has revised its technical course content is the Bartlett School. This was done along with a major revision of the whole curriculum in 1960. By 1966 there had been several changes in the teaching methods but no major change of direction. The approach, as presented at a conference in 1966 by Lord Llewleyn-Davies, shows stronger emphasis on a basic background in the technical subjects than any of the other schools.

> We believed that an architect's education too often led him to a facile approach of his problems and that he had little understanding of the depth in which an architectural problem should really be studied and little respect for the tools which the physical and social sciences now make available for the practice of architecture. We therefore considered it an important element in the design of our new course to foster an interest in science, an understanding and respect for the scientific method, and an ability to make use of the collaboration of a wide range of sciences as part of the task of being an architect. We therefore emphasized science to a considerable degree in the early parts of the curriculum, not for the purpose of turning our students into scientists or for imparting to them partial packages of scientific

> knowledge but to make sure they understood something of the nature and methods of science and its relevance to the problems of architectural design.
>
> The first lecture the students have on arriving is given by the Professor of Anatomy and deals with the human being. During the first year and much of the second a substantial volume of teaching is devoted to subjects which we believe basic to architecture. For example, the student is taught about the human being and his reaction to the environment, that is a good deal of human biology and psychology. They are taught about the physics of the environment and about sociological and anthropological methods for the study and description of man's behavior as a member of a group. During this period their work on problems in the studio is confined to problems abstracted from the totality of architecture so as to deal only with one, two or three facets related to the material that was being put before them in the lectures and seminars. As the course proceeds so the number of facets which we invite the student to deal with in problem solving in the studio increases and by the end of the third year they are dealing with multifaceted problems not far removed from complete architectural design.
>
> ...we have very recently decided on a rather drastic move. We feel that the dichotomy between 'design' in the studio and the other components of an architectural course is really the central problem, and that this dichotomy must be got rid of. We propose to do this by abolishing assessment of studio design as an independent measure of students' achievement. We propose to regard studio work as a mode of teaching and assess it only in relation to the subjects which it relates to. We are therefore forced to match problem solving in the studio with the taught subjects, and unless correspondence can be achieved at every point we will have to change the subjects taught, or the studio exercises, or both. [9]

These three schools seem to be getting at two major issues. These issues are: 1) having the courses taught to give an

[9] Llewelyn-Davies, "Integrating Education for Architecture, Building and Planning."

understanding of the basic concepts from the point of view of architecture and building and 2) making them relevant to architectural design in the design studios.

These schools have strong emphasis in the early parts of their courses on the theory, the nature and the behavior of the environment from the human perceptual point of view; they bring out the implications on architectural design; and they separate the theory, which is basic and relatively unchanging, from the practical solutions, which are rapidly changing with technological advances and changes in mode or style of construction.

The Bartlett School goes beyond this in dealing directly with the second issue. Here the design studio is used in the manner to which it is best suited--that of applying knowledge and acquiring skill. The studio has been placed in an almost subordinate role by assessing its products only in relation to the other courses. The effects of this approach are clear. By assessing the studio work in this way not only is the student given a better understanding of the application of the material from the other courses, but this material is integrated with architectural design.

Perhaps it is worth considering altering the role of the architectural design studio. At least, if the studio is kept in its present dominant role, the work produced should be evaluated in all architectural aspects, including environmental control.

CHAPTER IV

Alternative Approaches

Various schemes have been suggested to improve the teaching of the environmental control courses. In order to evaluate these schemes let us first define some objectives.

From the students' point of view, some of the things which they express that they would like to learn from these courses are:

- Enough knowledge about the subjects so that they can communicate intelligently with contractors or with the engineering consultants,

- Rules of thumb about environmental control systems and enough information about sizes of equipment and installations so that allowances can be made in the "design,"

- An ability to do rough analysis of the design so that the basic requirements of the environmental control systems can be approximated.

However, if we accept the notion that the architect is responsible for specifying or designing the human environment, he must be responsible for this environment in all of its aspects. He cannot merely be a form-giver and blame the failings of the thermal control or the illumination on the engineering consultants. This suggests that the architect should understand environmental design in all of its aspects including the environmental control aspects, i.e., the effect of form on the environment and the systems which control the environmental elements, such as the thermal, acoustic, lighting, and utility systems. (This doesn't mean that he must understand the design of the hardware.) Understanding these aspects of environmental control requires greater knowledge than the vocabulary to communicate with the consultants and contractors or the rules of thumb for allowing for equipment. Handbooks can serve this purpose. Restricting understanding to vocabulary and rules of thumb minimizes the implications the environmental control systems have on form, spatial relationships, and kinds of construction. A more fundamental understanding of the environment is necessary.

Considering the foregoing, we can list as objectives of the environmental control part of the curriculum as:

- to make the student aware of how the human senses and responds to the environment and therefore of a need to control the forces,

- to make the student familiar with the nature of the environmental forces and how they react with the building fabric,

- to make the student familiar with the methods of controlling these forces both with the fabric of the building and by means of additional energy,

- to make the student familiar with current practice in solving these problems, and the criteria used in these solutions.

Of the various schemes which are being suggested to teach the environmental control courses, there are perhaps two basic methods: 1) integrating the subjects into the studios, where the material is taught by means of technical critics who act like consultants to the students while the students are working on their studio exercises; 2) teaching the subjects in courses separate from the design studios.

The first of the two methods of teaching the environmental control courses, that of integrating the teaching into the design studios, has some serious drawbacks. The primary drawback is that the student may end up learning only how to solve several very specific problems, some perhaps in great detail and some only superficially. The result is that he will not be very well prepared to solve new problems when they come along. In order to solve new problems he must first generalize from his specific knowledge to find some basis on which to again particularize in the new problem. Unless he is able to arrive at a sound theory from which to again particularize, it is likely that he will end up by adapting an old solution to a new and different problem; a solution which can be inappropriate or even wrong.

Teaching by means of consultant/critics in the studio would make it very difficult to teach fundamental principles. The time spent on fundamental principles would have to be repeated with each student. The student might benefit from having his own tutor for this instruction but would lose from not having the interaction with other students, as in a classroom, bringing up points which have not come up between student and consultant/critic. The time spent with one student on the fundamentals could be better spent lecturing the whole class.

The basic issue here is one of matching the teaching method to the material being taught. The technical aspects--environmental control and structures--are fundamentally different from the part of architectural design that deals with the visual/spatial aspects. The former are based on a generally agreed upon body of knowledge which has a high degree of objectivity. These are things which can be measured, acted upon with predictable results, and which in general elicit human responses that are deterministic. (There is some degree of subjectivity with regard to people's response to various lighting, acoustic or thermal/humidity conditions due to their physiological differences, psychological associations or cultural backgrounds, but the threshold levels and comfort zones are relatively constant.)

The latter, on the other hand, is a much more subjective matter, and more importantly, lacks a universally accepted body of knowledge and theory of action and response. The distinction might also be seen as that which can be taught vs. that which cannot be taught but which must be learned.

These distinctions are well explained by Jerome Bruner in his discussion of the importance of the structure of a subject in education.[10] He writes about the two ways in which learning serves the future. One is through specific transfer of training, i.e., specific applicability to

[10] Bruner, Jerome S. The Process of Education, p. 17.

tasks that are highly similar to those already learned. It might also be called the extension of habits or associations. An example Bruner gives is that having learned to hammer nails, we are better able to later learn how to hammer tacks or chip wood. This method is useful in learning skills. The second way is called non-specific transfer or transfer of principles and attitudes. It consists of learning initially not a skill but a general idea which can then be used as a basis for recognizing subsequent problems as special cases of the idea originally mastered. "This type of transfer is at the heart of the educational process--the continual broadening and deepening of knowledge in terms of basic and general ideas."

Because the visual/spatial aspects of architectural design do not have a clearly defined set of basic and general ideas vis-a-vis the technical subjects, they can only be learned by means of acquiring skill in designing and, through this experience and criticism by others (design critics), gain insight into some personal basic and general ideas about the subject. Lacking a generally agreed upon body of knowledge about these aspects, the studio is the only way in which they can be taught.

The technical subjects, on the other hand, have a well defined set of basic and general ideas. There is some clear structure to the subject matter. If these subjects are to be effectively utilized in architectural design, it is imperative that the student get a good foundation in the structure of the subject matter. In Bruner's words, "...in order for a person to be able to recognize the applicability or inapplicability of an idea to a new situation and to broaden his learning thereby, he must have clearly in mind the general nature of the phenomenon with which he is dealing. The more fundamental or basic is the idea he has learned, almost by definition, the greater will be its breadth of applicability to new problems."[11]

Seminar sessions associated with the studio problems to deal with the basics of the technical subjects have been suggested to obviate the difficulties of dealing with them in the studios. This would not be very effective from the standpoint of the volume of the material. If it were adequately dealt with in these seminars, it would be essentially the same as the (earlier mentioned) method of teaching the subjects in courses separate from the studios.

Other drawbacks of completely integrating the teaching of the technical subjects with the design studios are that

[11]Bruner, Jerome S. The Process of Education, p. 18.

there would have to be restrictions on the kinds of architectural design problems used in the studios and in the choice of studio by the students. Design studios frequently are such that many of the environmental control issues are not involved. In order to provide a sufficient range of environmental control issues so that the student can deal with new problems when they come up, the problems must be carefully designed so that they will bring out the pertinent issues of all the subjects which it intends to teach. The students would have to be assigned to studios that cover the issues they have not previously studied.

This brings us to the second method mentioned above, that of teaching the course separately from the design studios. Some of the advantages of using this method have already been enumerated in the discussion of the learning process. In addition, it allows the material to be covered in a more consistent manner (by not being dependent on the design studios) than if the topics covered were a function of the current problems in the studios. This does not mean to imply that the environmental control courses should ignore the problems as they occur in the design studios; on the contrary, discussing these as they occur will help to show the relevance of environmental control to architectural design.

The disadvantage of this method is that unless the courses are made truly more relevant to architecture, they will end up with the same problems as in the existing courses. These problems are not inevitable. Teaching the environmental control subjects separately from the design studio offers the best chance of adequately covering the material and at the same time makes it relevant to architectural design. A proposal for a way to organize such a course sequence follows in the next chapter.

CHAPTER V

Proposal for a New Course Sequence

There are many variables involved in the actual implementation of such a sequence which will influence its effectiveness, e.g., individual differences in personality, experience, attitudes about architecture among the faculty, and availability of the staff to teach. This thesis does not deal with these factors. What it hopes to do is to propose an approach to teaching the environmental control and related mechanical systems at M.I.T. in order to satisfy the earlier stated objectives (and in a form independent of the above variables).

This discussion will include the philosophy of the approach, the organization of the material, some of the teaching methods which should be used, and finally, the relationship of the sequence to the rest of the curriculum.

The philosophy behind the course sequence should be:

1) to progress from the basic fundamentals of the behavior of the environmental forces, human and material response, to the methods of controlling these forces, first passively and then actively,

2) to separate theory and fundamentals from equipment and hardware,

3) to deal with the theory of the different environmental forces or energies in parallel with each other as much as possible,

4) to limit mathematical conceptualization to the demonstration of relative importances of concurrent effects and of orders of magnitude, and to emphasize visual conceptualization.

To adapt the M.I.T. program to this new course sequence, a rearrangement of the topics now covered would be required.

Building Processes and Engineering Materials should be eliminated as separate courses and the topics which they cover be divided between the existing structures sequence and the new environmental control sequence. Most of the material in these two existing courses can be divided into the categories of: 1) the supporting of loads and the properties of materials related to load supporting, and 2) the environmental forces, their control and the properties of materials related to environmental control. This reorganization would eliminate spending time on an introductory course briefly covering many topics and would substitute one which introduces more fundamental concepts and establishes the context for subsequent courses. It would also relate the study of materials to both the structural and environmental control context rather than to the engineering context. The only topics which this arrangement does not cover are the construction details and Critical Path scheduling now in "Building Processes." These might be covered in a separate course.

Following is a general topic outline in an order which gives **emphasis** early in the sequence to the fundamentals of environmental control and leading to more specific solutions and hardware.

1. Nature of the environmental forces, elements, energies, i.e., sound, light, heat, air and air motion, water and water vapor
   - how they occur, how transmitted, flow, move, and react with each other,
   - similarities and differences between the various forces
   - how they are measured, quantified.
2. Human response to the environmental forces
   - human perception of each of the forces
   - limits of tolerance and thresholds of perception
   - regions of comfort and the variations of these regions with culture, climate, age, race, etc.
   - need to modulate and exert control over the environment

3. Response of material to the environmental forces (this is touched on in the first section about the transmission and flow)
   - kinds of materials, i.e., solids, liquids, and gasses and something of the nature of the structure of material as related to its behavior in the environment
   - interaction of the environmental forces and materials, such as transmission/impedence, absorbtion, reflection, radiation
   - properties of common building materials as well as desirable properties of hypothetical materials which might better control or modulate the environmental forces

4. Passive control of the environmental forces
   - environmental fabric assembled as systems to modulate the environmental forces without use of supplementary energy. Demonstrating that the architect's "things" (form, materials, surface properties, etc.) can substitute for hardware
   - determining when passive control is inadequate to control the environment or conflicts with other architectural criteria, thus requiring the supplemental energy (i.e., the need for active control)

5. Principles of active control of the environmental forces
   - where the supplemental energy is best placed
   - principles of control systems, i.e., information flows, power flows, automatic and manual control

6. Methods of providing active control
   - energy sources and methods of distributing energy
   - elements which use the distributed energy to help modulate the environmental forces--heat dissipating and absorbing units, air moving units, sound amplifying units, light sources and fixtures (essentially, the utility elements related to control of environmental forces)
7. Utilities in a building system
   - the principles of behavior of the utility elements
   - water supply and distribution, liquid waste disposal, solid waste disposal, electrical power distribution, communications systems, distribution systems for objects and people
8. Hardware used in implementing all of the above controls and utility systems
   - systems in current use
   - innovations, and explanations of reasons for obsolescence of systems no longer used
   - specific information with regard to capacities, space required, relative costs, influence on form of building
   - rules of thumb and use of handbooks.

The reason for this subject organization is twofold. It presents the topics in a way best reflecting the structure of the body of knowledge of environmental control, and it presents the information from the point of view of the field which will apply it, i.e., designing the environment for human habitation and use.

Again quoting Jerome Bruner on general claims that can be made for teaching the fundamental structure of a subject,

> ...understanding fundamentals makes a subject more comprehensible. This is true not only in physics and mathematics,...but equally in the social studies and literature.
>
> [It]...relates to human memory. Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten...
>
> ...to understand something as a specific instance of a more general case--which is what understanding a more fundamental principle or structure means--is to have learned not only a specific thing but also a model for understanding other things like it that one might encounter....[12]

The value of teaching the topics from the human environment point of view is obvious. An advantage is that it minimizes one of the problems in teaching these subjects: that of teaching students with a wide variety of educational backgrounds and levels of technical competence. These backgrounds range from engineering and science to liberal arts. Looking at the information from a point of view different from science and engineering will provide a different context and a new application of the facts for the technically trained students (lessening the chance of boring them) while not going over the heads of the others.

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[12]Bruner, Jerome S. The Process of Education, pp. 23-25.

Teaching all of the environmental forces in parallel is desirable because it will bring out the similarities and differences between the forces and point out their relationships in the larger structure. For instance, light and sound are both radiated energy, both can be reflected and absorbed, both are refracted when being transmitted through media or changing densities. However, one is dependent on a medium for transmission while the other is not, and their wavelengths are orders of magnitude apart, determining the scale of things which reflect and refract them.

This organization, however, presents a problem when trying to find qualified people to teach this course. It is very unlikely that one person can be found who has the knowledge and experience to teach the whole course sequence or even to teach sections of the course covering all of the environmental forces in parallel. The knowledge and experience of most people who might be found to teach these subjects is vertical in one of the areas of environmental control rather than horizontal across all of them, as would be desirable. In order to accommodate this situation, there will have to be some vertical separation of the topics into the more conventional areas of environmental control: thermal, acoustic, and illumination. This vertical separation could occur somewhere in sections 4 or 5 of the general topic outline, leaving the first few sections together to be taught in parallel. The exact place where the vertical separation occurs is dependent to a large extent on the person found to teach each section.

A modified organization to take care of this situation would start with an introductory section followed by sections covering acoustics, illumination, and thermal control. The introductory section should concentrate on the fundamental aspects of all the environmental forces, the relationships between them, the relationship with architectural design and set the context for the succeeding sections. The other sections should follow the general outline wherever it applies to each area. The sequence should be coordinated by one person (to insure continuity and relevance) who should also teach the context-setting first section.

It is important that the people who teach these courses understand enough about the function of the architect in designing buildings, including what the architect thinks his function is, to insure that the course will be oriented to the architect and taught in terms which he will best understand. Ideally we might say that these people should have architectural training as well as the specialized training in the field in which they are experts. Architectural training is not frequent among the experts in the environmental control areas, however, there are some, e.g., Robert B. Newman, who already teaches acoustics, and William M.C. Lam, in lighting. The person who teaches the introductory course at least should be an architect-turned-environmental-control-teacher so that proper context is set and he is able to coordinate the succeeding courses.

Following is a more detailed topic outline separating the environmental control into the areas as they would probably be taught. This outline is not a complete list, but illustrates the organization by the major topics.

I. Illumination and lighting

- A. natural illumination-sunlight and sky light
  - sun motion
  - control of sunlight, sunshading, relation to thermal control
  - measures of illumination, physical and perceptual
  - use of light as a design element
  - response of various materials to light
- B. Artificially produced illumination
  - need for supplying supplementary illumination
  - physiological and psychological effects of different kinds of lighting
  - methods of producing different kinds of illumination

- types of light sources
- methods of controlling the light sources
- kinds of equipment available and in current use

II. Acoustics

- nature of sound, free field propagation, reverberation time
- how produced and measured
- human perception, noise levels, masking noise
- noise reduction in rooms, reflection, absorbtion
- sound transmission through walls
- equipment and structure-borne noise
- criteria for hearing
- effects of shapes of rooms
- sound amplification systems

III. Weather Elements

- nature of weather elements--wind, precipitation
- moisture penetration into the building fabric
- reaction of materials to moisture
- effects of wind on interior environment of a building, i.e., drafts, infiltration, ventilation, air changing, chimney draft
- effects of buildings on the local wind patterns
- methods of controlling wind and moisture

IV. Thermal Control

- nature of heat
- how measure, relation of temperature and heat
- humidity, evaporation, latent heat and its effect on temperature
- psychrometric chart

- transmission of heat by conduction, radiation, and convection
- human response to temperature, humidity, radiation and air movement
- comfort zones--Olgyay's chart, ASHRAE Comfort Chart
- heat sources in a building--human, appliances, machinery, lights, sun
- how materials respond to heat in steady state and under dynamic conditions
- passive control using the fabric of the building
- defining where passive control is not sufficient or in conflict with other criteria
- how extra energy can add control to the thermal environment
- introduction to the systems that can be used for active control.

Implementing this outline is to some extent dependent on the persons doing the teaching, although there are some general things to be said about the type of class session and teaching techniques best employed.

There are some fundamental differences between the effectiveness of lecture and discussion class sessions. Wilbert McKeachie, a psychologist, discussing this in the 1963 Cranbrook Seminar, referred to several studies comparing lecture and discussion classes.[13] Lectures are much better at conveying specific information although discussions

[13] McKeachie, Wilbert J. "Psychology and College Teaching...."

are better for later recall, concept learning, and in effecting attitudes toward the material. Two of the reasons for this are that in discussion the student spends more time in active thought than in a lecture, and he gets feedback on these thoughts.

This suggests that the class should be some combination of the two, since there is a significant amount of specific information involved in environmental control for which lectures are especially suitable.

Other ways to illustrate principles and applications are through demonstrations, field trips, case studies, and design problems.

Demonstrations can usually be done with materials or conditions which exist in and around the school. Since it is the environment and its control which is to be demonstrated, it is likely that almost every effect of the environment can be found nearby. Needed to make the demonstrations have greater meaning is equipment to measure the phenomena. The human body (which all of the students have) is a good detector of many of the environmental forces. However, it doesn't have a very good scale for measurement. Instruments such as sling psychrometers, illumination meters, sound level meters and wind velocity meters can demonstrate many of the fundamental concepts of the environmental forces.

In addition to these 'real' world examples of 'found' conditions, it would be desirable to have a laboratory which can be used to demonstrate and illustrate phenomena or conditions which do not commonly occur or are not easily found. It would be instructive to be able to demonstrate, in the thermal area for instance, the comparative difference between radiant heating in the ceiling and in the floor or how by increasing the mean radiant temperature, the air temperature can be lowered. To do this in real world found situations would be difficult. By the time the class traveled from one condition in one building to the other they would have gone through many intermediate conditions making the comparison difficult. Alternatively it is difficult to find a place where both mean radiant temperature and air temperature can be manipulated rapidly over wide ranges except in a laboratory.

A place for a laboratory for these things might be a room big enough to both use as a laboratory and to hold class sessions having many changeable elements. These elements should include a variety of heating systems such as radiant (ceiling, wall, floor), hot air with various inlets and exhaust locations, baseboard convectors, windows with a southern exposure and changeable glass (plate, thermopane, heat absorbing, etc.), possibilities of attaching sunshades in a variety of ways, external and internal shading; a variety of acoustical treatments which can be placed on the walls and ceiling to alter the acoustics of the room including examples of amplifying systems and masking noise; and a variety of illumination sources which can be moved and selectively adjusted.

In addition to demonstrating environmental control principles, there also should be a variety of utility equipment which can be manipulated. For instance, plumbing fixtures to show the use of traps and need for venting, electrical circuits with fusing and grounding illustrated, etc.

Although a laboratory is not as important as the real world demonstrations, it can serve to more dramatically demonstrate many of the principles.

Field trips and case studies can be used together to illustrate both the fundamentals of the environmental control and the applications in solving the problems. The field trips should be preceded by a study of the buildings in order to make the trip meaningful. It is important to include among the case studies and field trips examples of both good and bad solutions of environmental control, and in particular, buildings which are considered "good"architecture, being visually exciting, but which have problems with the environmental control resulting from failure to consider the issues in the "architectural" design stage.

The focus of these studies and trips should change as the sequence progresses so they highlight the current phase of the sequence. For instance, in the earlier stages the way the environmental forces act on a building and the way the building modulates them (or doesn't) should be emphasized, while in the later stages the emphasis should shift to the methods of solution, and finally to the equipment.

Finally there is the matter of the relationship of the environmental courses to the rest of the curriculum. More specifically, the application of the material learned in these courses in architectural design. This relationship must be that of one being part of the other, rather than separate from each other. If applications are neither indicated in the teaching of environmental control nor encouraged in the design studios, the material will have little lasting meaning and will soon be forgotten.

In order for the students to learn those applications there should be short design problems given in the environmental control classes. These should be restricted in scope to demonstrate and give skill in dealing with specific aspects of environmental control as they are related to architectural design. Good examples of this taken from Murray Milne's course are the design of sun shading elements to give very specific illumination in a room and the design of a habitable room which depends only on the fabric of the building to modulate the forces to make a comfortable environment.

But more important is the application of this material in the architectural design studio. Unless this is done there will only be a reinforcement of the separation of architectural design and environmental control--a separation which in theory does not exist.

To insure the application in the design studios there must be collaboration between the design faculty and the environmental control faculty to form what might be called a design critic team. This team would, of course, also include all of the other facets of architectural design, e.g., structural, sociological, planning, etc. It would allow consideration of environmental control issues (plus all of the other facets) both in the day-to-day criticisms and the final juries, and for those issues to be considered in evaluating the students' work.

Environmental control can not be ignored in architectural design. It must be taught in a manner which is both relevant to architecture and in a way which the architect can understand. There needs to be a revision in the teaching approach if this is to be accomplished.

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APPENDIX

Course Descriptions from M.I.T. General Catalogue 1968-69

4.402 Building Process
Prereq:--
Year: U(2) 3-3-6

Principal building systems as affected by environmental and legal conditions, materials, and industrial constraints. Interrelationships among the parts of the system. Fundamental systems of enclosure, load distribution and environmental control; air, heat, light, sound. Assembly processes and principles of project control. Problems, projects and field trips to illustrate principles.

Dietz

1.02 Engineering Materials
Prereq: 8.01
Year: U(1,2) 3-3-6

Principles underlying the structure-properties interaction in materials important to civil engineers. Topics including atomic arrangements in crystalline and non-crystalline phases; thermodynamics of phase relationships and structural change; elasticity, microplasticity, viscoelasticity, and fracture; corrosion. Application of principles to structural metals, cementitious materials, structural ceramics, wood, asphalt, and polymers. Mechanical properties of composite materials, including Portland cement concrete, asphalt-aggregate mixtures, and reinforced plastics. Laboratory work on the common techniques used in the study of microstructure and in the determination of mechanical properties. (Fall term--recommended for Course IV students. Spring term--recommended for Course I students.)

Jones, Williamson

4.42T Materials
Prereq: 1.02
Year: U(2) 3-2-3

Emphasis on newer materials and combinations. Development of properties and applications from fundamental structure of materials. Plastics and other polymeric materials. Engineering adhesives and principles of bonding. Wood derivatives and bonded structures. Ceramics. Glass. High-performance masonry. Metals and alloys. Composites of several materials: fiber-reinforced, laminates, and sandwiches. Principles of combined behavior. Deterioration of materials, protection against attack.

Dietz

4.43 Environmental Control-Acoustics
Prereq: 8.02
Year: U(1) 3-0-5

Principles of acoustical design for good hearing conditions and control of noise in rooms and buildings; design criteria; analysis of sound absorption and transmission; acoustical properties of room shapes, structures, and surface materials; laboratory demonstrations.

R. B. Newman

4.431 Special Problems in Architectural Acoustics (A)
Prereq: 4.43
Year: G(1 or 2) Arr.

Broad study of functional acoustic design in architecture (based on project work in actual buildings where possible), sound distribution and diffusion in rooms, and sound transmission through building structures.

R. B. Newman

2.644 Environmental Control--Air Conditioning
Prereq: 8.02
Year: U(2) 3-0-5

Primarily for students in Architecture. Physiological and functional aspects involved in producing and controlling a thermal environment. Relationship of space and enclosure to climate and weather. Development and analysis for heating, cooling, ventilation, and air distribution. Principles and techniques of cooling. Evaluation of allocation of space for equipment and systems in the building source and conveyance media. Lecture material supplemented with plantand site trips.

Hesselschwerdt